Original

Fire Endurance of Surface Densified Wood of *Albizzia falcata* Treated with Fire Retardant

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Abstract——Bending strength and creep behavior under fire of solid wood, laminated veneer lumber (LVL) and glued-laminated timber of albizzia (*Albizzia falcata* Backer) coated with fire retardant and hot pressed (surface densified) at several temperatures were evaluated. Chemical used was trimethylolmelamine mixed with phosphoric acid coated at the amount of 100 g/m^2. Results showed that the fire endurance (time to creep rupture) of surface densified albizzia treated with the chemicals was improved, compared to that of untreated ones. Temperature of hot pressing of 160°C resulted in the longest time to creep rupture. Bending strength of woods was not affected when pressed at the temperature below 200°C.

Keywords : fire endurance, bending strength, creep behavior, *Albizzia falcata* Backer, surface densified wood

1. Introduction

Fire retardants are generally applied to wood in two conventional methods, by surface coating or by pressure impregnating[1,2]. Surface coating may increase ignition time and reduce flame spread but only contribute a slight increase in fire endurance compared to that of pressure impregnating. A new method by additional treatment with hot pressing after coating with fire retardant was found to improve the fire endurance[3]. Due to the hot pressing at a certain temperature, polymerization of fire retardant occurred at the surface of wood. This will densify the wood and makes the fire retardant inert on the surface. A similar technique has been used to produce fire retardant particleboard[4]. This technique is simple and inexpensive because it only involves coating and hot pressing, and other equipments such as vacuum, impregnating or drying equipments are not required.

In the present experiment, albizzia, one of the important fast growing tree species planted in tropical countries such as Indonesia and Malaysia, was used. The wood usually used for non-structural purposes. However, by using a certain technique such as glued-

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laminating, it can be modified as structural materials. In the application, wood used as structural materials always support a certain amount of load. When fire affect such materials, it is important to observe the creep behavior of wood under such load and expose to fire at the same time[5]. Fire retardant used was mixed with trimethylolmelamine and phosphoric acid. It is well known that such combination of melamine and phosphorous compounds have been proven to be effective to improve fire endurance of wood materials[6,7]. The present study observes the effects of hot pressing temperature on bending properties and on their creep behavior under fire.

2. Methods and Materials

2.1 Preparation and treatment of wood samples

Samples were prepared from albizzia (*Albizzia falcata* Backer) originated from Indonesia and Malaysia, LVL and glued-laminated timber obtained from AICA KOGYO Co. Ltd.. The LVL were made with the lamination of three 5mm-layer with the grain parallel. Resorcinol adhesives were painted between the surfaces at the amount of 200 g/m^2 and the samples were cold pressed for 24 h. Sample size of 15 mm×40 mm×400 mm were prepared from those samples for bending test, and creep test under fire. The number of replication was one for solid wood and glued-laminated timber samples and two for LVL ones.

Fire retardant was prepared by mixing powder of trimethylolmelamine and 85% solution of phosphoric acid with the molar ratio of 1 : 1.5, and water was added to make 40% solution. The final solution was clear with a pH value of about 2.5.

Samples were coated with the fire retardant on the wide surfaces at the amount of 100 g/m^2. The retardant cured at room temperature and then the samples were conditioned for about a week. All treated samples were hot pressed for 10 min at a pressure of 50 kg/cm^2 that was supported with 15-mm high distance bars. The solid wood and LVL samples were pressed at the temperature of 160°C, 200°C and 240°C, and glued-laminated timber samples were pressed at temperature of 160°C, 180°C, 200°C and 220°C.

2.2 Testing

The span for bending tests was 360 mm. Maximum load, modulus of elasticity (MOE) and modulus of rupture (MOR) were determined from the load-deflection curves. Creep test under fire was conducted using the apparatus shown in Fig. 1. Each sample was set as illustrated and a 10% of maximum load was applied to the sample based on the results obtained from the bending test. Initial deflection was recorded. Fire from gas burner with a top flame temperature of about 850–900°C was applied to the center of the sample without air supply. This was done continuously until failure occurred. Deflection was recorded every 10 s and time to rupture was also determined.

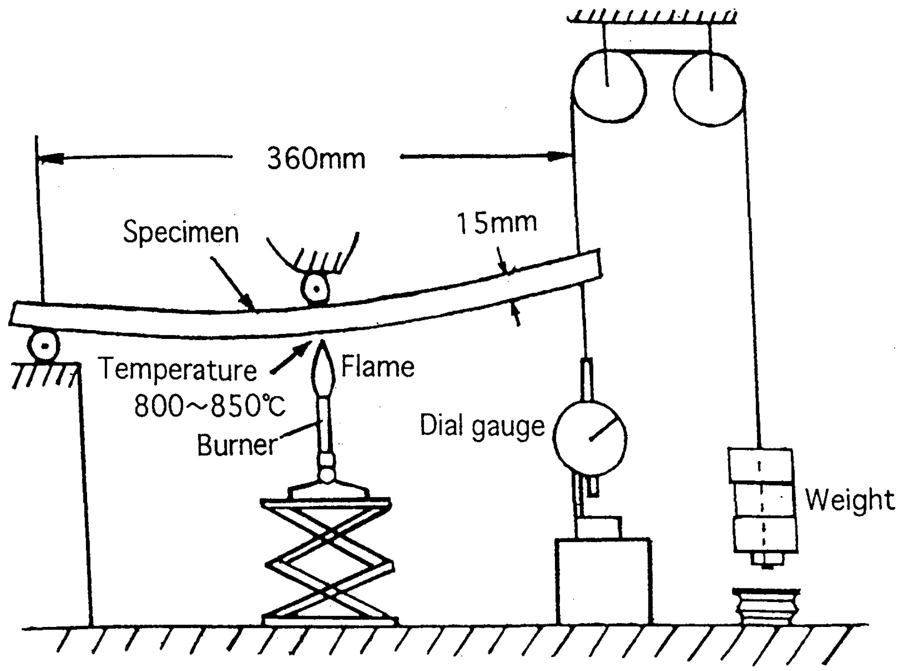

Fig. 1. Apparatus of creep test under fire.

3. Results and Discussion

3.1 Bending test results

Results of bending test of solid wood, LVL as well as glued-laminated timber of albizzia are presented in Table 1. MOE and MOR of the solid wood and LVL are not quite affected when hot pressed at the temperatures of 160°C and 200°C compared to those of untreated samples (without hot pressing). However, when hot press was applied at the temperature of 240°C, the MOE and MOR values decreased. Visual observation of the samples pressed at the temperature of 240°C showed changes in colour to dark black in the surfaces. This may be due to the thermal degradation of wood composition and burned chemicals[1]. This was in contrast with samples pressed at the temperatures of 160°C and 200°C, of which surface colour was changed to light brown.

Similar trend was observed in glued-laminated timber. The MOE and MOR values were relatively not affected when hot pressed at 160°C, 180°C and 200°C, even though a slight decrease in the values was observed, compared to untreated samples without hot pressing. But a significant decrease of MOE and MOR values were observed when hot pressed at 220°C.

It was observed from the present experiment that surface treatment with the chemicals and followed by hot pressing at different temperatures have minor influence on bending strength of albizzia when applied at the temperature of less than or equal to 200°C. Densification and polymerization of fire retardant chemicals occurred at the surface of

Table 1. Bending test results of solid wood, LVL and glued-laminated timber of albizia after coating and hot pressing.

Temperature of Hot Pressing	Density (g/cm^3)	MOE (MPa)	MOR (MPa)
Solid wood			
Untreated	0.23	5168.1	29.46
160°C	0.27	5432.9	33.37
200°C	0.30	5629.0	42.09
240°C	0.20	4658.2	23.63
LVL			
Untreated	0.28	5746.7	35.29
160°C	0.27	5501.5	34.97
200°C	0.32	6001.7	49.20
240°C	0.28	4991.6	31.39
Glued-laminated timber			
Untreated	0.42	5687.9	42.44
160°C	0.35	4972.0	31.19
180°C	0.35	5325.0	34.97
200°C	0.37	5609.4	30.74
220°C	0.32	4834.7	26.61

Note: Untreated samples were not hot pressed. Values were averages of two samples.

samples. The greater densification and the decomposition of wood were balanced at the surfaces. On the other hand, when hot press was applied at the temperature of more than 200°C, a reduction in bending strength was observed compared to untreated samples without hot pressing due to the greater degree of the wood decomposition.

3.2 Results of creep test under fire

Relationship between exposure time and deflection of solid wood and LVL of albizzia are illustrated in Fig. 2 and Fig. 3, respectively. Whereas, such relationship of albizzia glued-laminated timber is presented in Fig. 4.

The temperature of hot pressing of 160°C resulted in the longest time to rupture in solid wood samples (Fig. 2). On the other hand, a small difference in time to rupture was exhibited between untreated samples and those pressed at temperature of 200°C and 240°C. Almost the same result was observed in the LVL samples (Fig. 3). Samples hot pressed at temperature of 160°C resulted in the longest time to rupture, followed by samples at temperature of 240°C and 200°C, and untreated samples resulted in the shortest time to rupture.

In albizzia glued-laminated timber samples, the longest time to rupture was resulted in samples hot pressed at temperature of 160°C, followed by temperature of 200°C, 220°C,

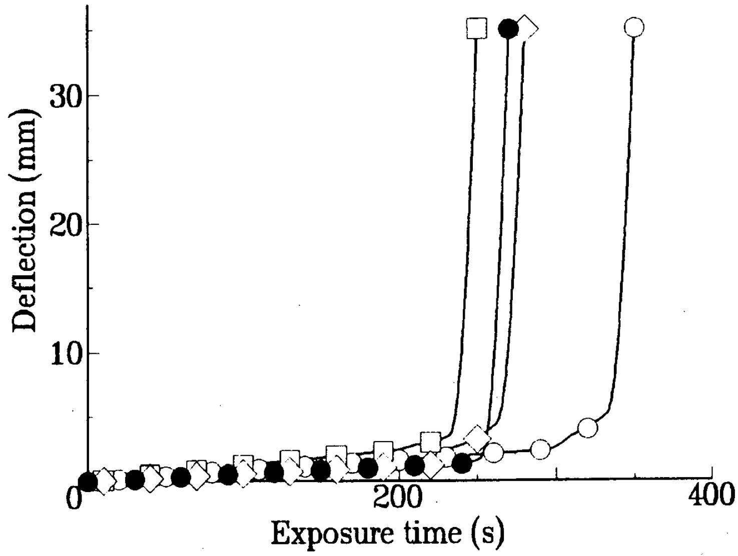

Fig. 2. Effect of exposure time on the deflection of solid wood as a function of time.
Note : Pressing temperature ○ : 160°C, □ : 200°C, ◇ : 240°C, ● : Control.

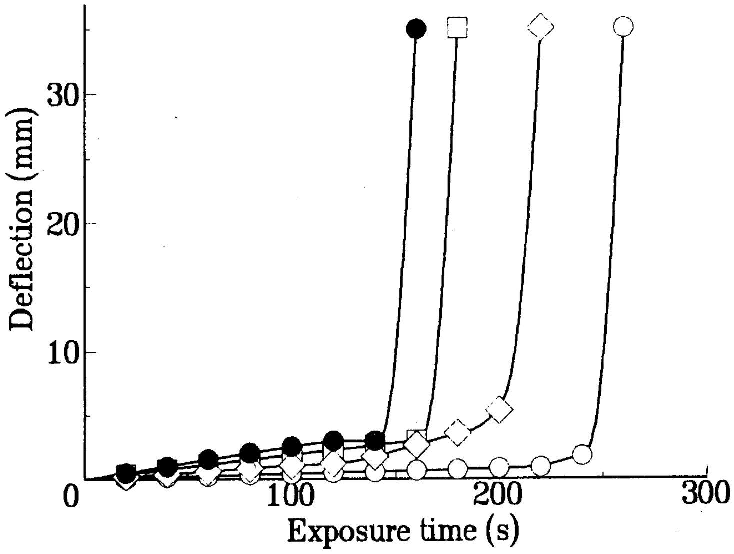

Fig. 3. Effect of exposure time on the deflection of the LVL as a function of time.
Note : Pressing temperature ○ : 160°C, □ : 200°C, ◇ : 240°C, ● : Control.

180°C, and untreated samples have the shortest time to rupture (Fig. 4).

It can be seen that for all samples, increase in time to rupture was observed due to treatment compared to untreated samples, except for the solid wood samples pressed at 200°C. This is an indication that the fire retardant chemicals used in this experiment was effective to improve fire resistance of wood products. On the surface of the treated samples,

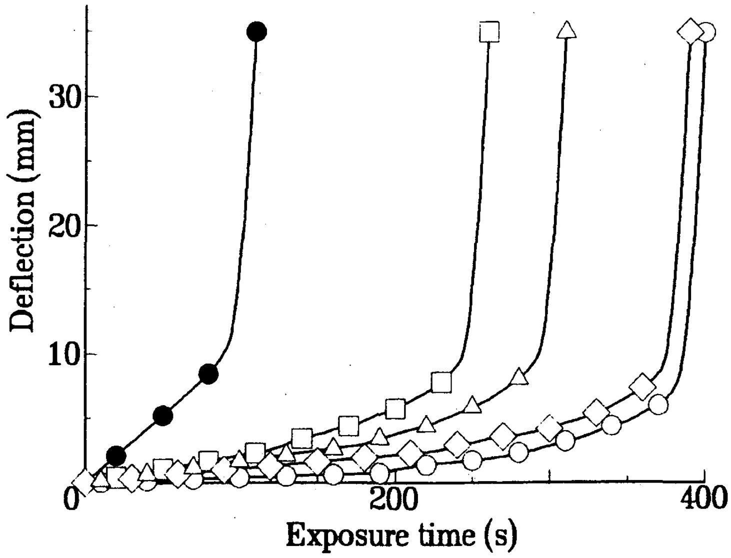

Fig. 4. Effect of pressing temperature on the deflection of glued-laminated timber as a function of time.
Note : Pressing temperature ○ : 160°C, □ : 180°C, ◇ : 200°C, △ : 220°C, ● : Control.

a char was developed due to the chemicals when fire progressed through which retarded the spread of fire[5,8]. It was also observed that among the pressing temperatures applied for 10 min in this experiment, temperature of 160°C resulted in the longest time to rupture. Probably the optimum polymerization of the chemicals and densification of the samples occurred at this temperature. Further experiment should be conducted to observe variation in duration of pressing time at several temperatures to clarify this result.

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